ISRU Overview

Presented to the Space Fabrication and Repair Workshop

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Context for Space Resource Utilization

- Replace materials that otherwise would have to be brought from Earth
  - Transportation cost
  - Delivery time
- Systems must provide significant mass replication advantage
  - Produce 100 – 1000 times mass (including replacement parts) in their operational lifetime

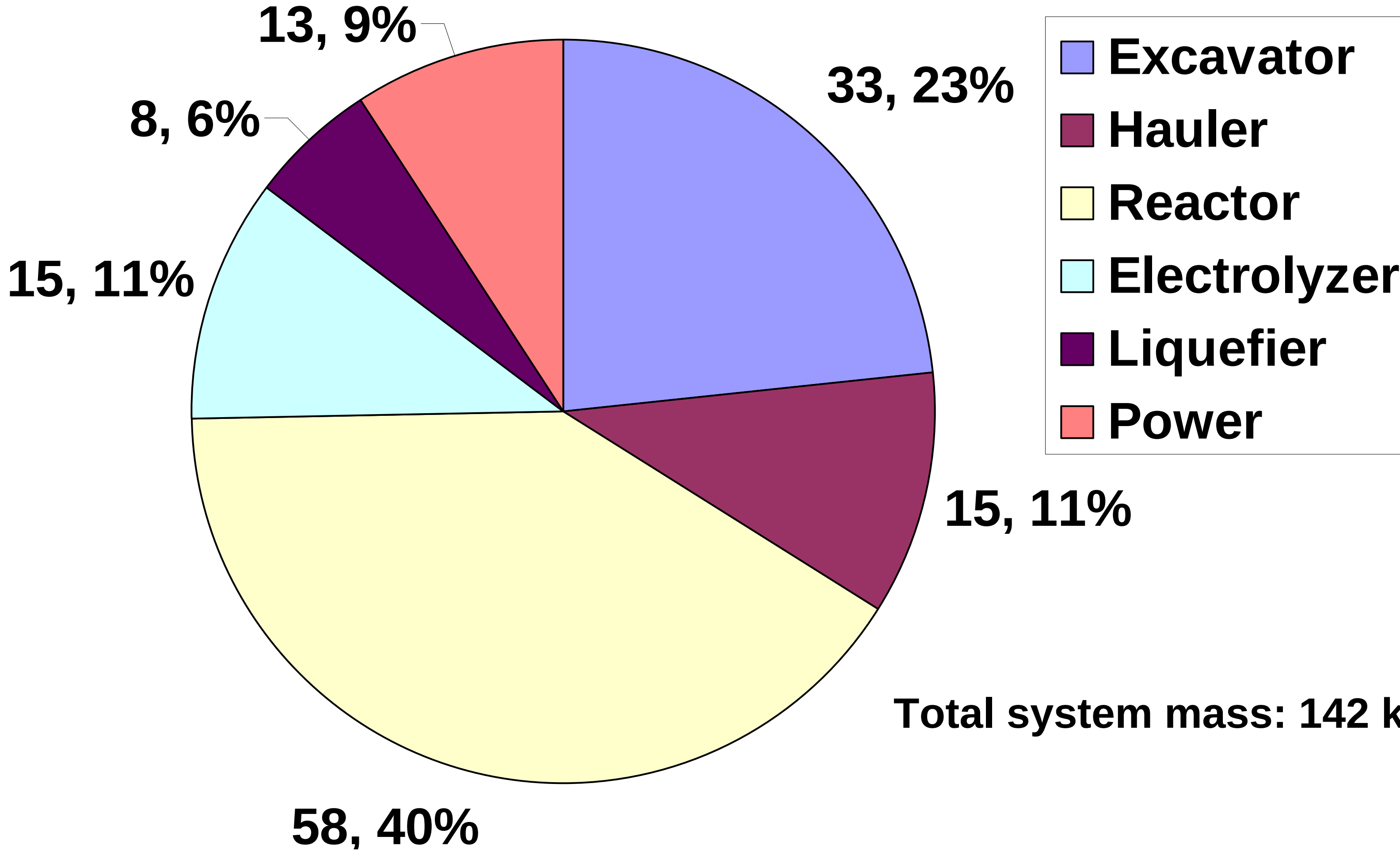
Hierarchy of Needs

- Propellant
  - Large masses required, relatively easy to produce
  - Used within transportation system, reduces cost of multiple missions to same location
- Energy production and storage
  - Significant masses for long-duration missions
    - Fuel cell reagents
    - Solar cells; solar concentrators
  - Reduces cost of adding new production capacity
- Radiation shielding
  - Direct use on planetary surface, or transport into space using ISRU propellants
- Life support consumables
  - Relatively small masses, but larger reservoirs increase robustness
- Metals, ceramics, etc.
  - Many uses (e.g. construction, manufacturing, electrical conductors)
  - Most individual uses are limited in demand
  - Repair, spare parts fabrication, etc. based on schedule, not mass

STATUS of ISRU Research

- Research in ISRU has been hampered by lack of commitment to long-term human space exploration
- Conceptual work done in 1970s has only been improved in a few areas
  - ISRU for Mars sample return
  - Improved robotic exploration systems
  - Relevant applications in advanced life support
  - Microchannel reactors
- A concerted program is required if mission designers can be expected to include ISRU in real programs

Oxygen Production from Lunar Pyroclastic Glass - 100 kg/month



Total system mass: 142 kg

Daylight operations equivalent to ~ 30 % system operating time
Power assumed provided by solar array – 2 kg/kW

Enabling Technologies

- Efficient, long life, low maintenance excavation and material transfer systems
- Efficient reactors for volatile extraction from regoliths of Moon, Mars, small bodies
  - Effective sealing systems for vacuum operations
- Efficient reactors for high-temperature processing of materials to produce metals and ceramics
  - Techniques for recovering reagents, electrodes
  - Long-lived systems, such as non-reactive electrodes
- Gas separation (membranes, condensors, absorption, distillation, etc.)
- Efficient heat exchangers
- Process miniaturization; energy efficiency
- Improved process sensor and control
- Cryogenic fluid liquefaction, storage and transfer systems
- Manufacturing techniques (solar cells, wires, structural materials)

ISRU Activities at CSM

- Modeling of propellant production from lunar regolith (O_2, H_2+O_2) and polar ice (H_2O, H_2, O_2), Mars regolith, Phobos (or carbonaceous asteroid) regolith
- High mass efficiency bucket-wheel excavator
- Microwave reactor for extraction of ice

Why a Bucket-Wheel Excavator

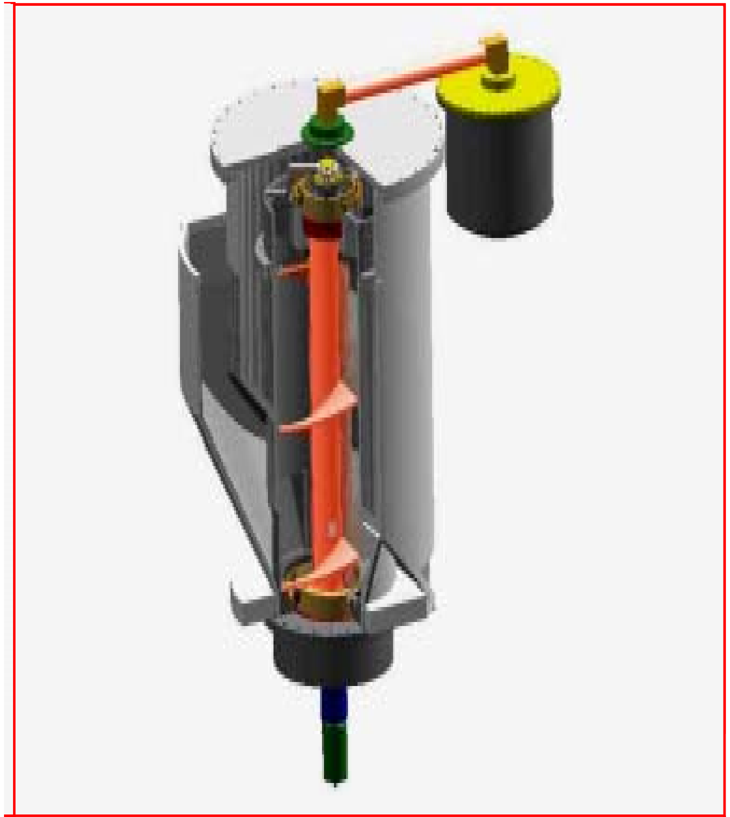
- Previous modeling of lunar excavation has focused on front-end loaders (EEI, 1988)
- Characteristics of bucket-wheel excavator vis-à-vis FEL
  - Bucket wheel system is simpler, fewer parts
  - Forces are primarily horizontal, not vertical
    - Ideally suited for low-gravity environment
    - Bucket-wheel mass used to increase traction
  - Continuous excavation provides optimum system mass/excavation rate – high duty cycle – loading/unloading are integrated
  - Easily integrated with hauling system
  - Bucket wheel width can be small, allowing flexibility with respect to large rocks

Bucket-wheel Excavator Test Bed

Lunar Ice Extraction Furnace

Initial reactor design based on auger moving material past a centrally heated core
- **heating is inefficient**
- **residence time is long**

Alternative designs under study utilize microwave energy to heat material
- **rapid heating of grains**
- **extraction does not depend on diffusion, so residence time can be short**



Conceptual design of CSM lunar ice extraction furnace